USAARL Report No. 95-37

Effects of Head Supported Devices on Pilot Performance During Simulated Helicopter Rides

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September 1995

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Fort Rucker, Alabama 36362-0577

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 95-37	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) MCMR-UAD	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Materiel Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 620577 Fort Rucker, AL 36362-0577	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick MD 21702-5012
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62787A	30162787A878	EB	142

11. TITLE (Include Security Classification)
Effects of head supported devices on pilot performance during simulated helicopter rides

12. PERSONAL AUTHOR(S)
Nabih M. Alem, Martin D. Meyer, and John P. Albano

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM TO		

16. SUPPLEMENTAL NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
helmet mass, helmet-mounted, pilot performance, vigilance

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Effects of helmet weight moments on helicopter pilot fatigue and performance during extended missions were evaluated in a study in which 12 volunteer subjects were exposed to random vibrations in 4-hour sessions while wearing various helmet configurations. One of the objectives of the study was to investigate an upper limit criterion of 83 N cm for the weight moment of head-worn devices previously proposed by Butler (1992). In this study, four helmet configurations, having weight moments of 20, 110, 200, and 290 N cm, were tested with each subject. Detection and acquisition of visual targets, a task often performed by AH-64 helicopter pilots, were simulated by requiring the subject to aim a light beam, emanating from a helmet-attached source, at light emitting diodes (LED) which were lit at random. Vigilance of the subject was measured by the duration the LED remained lit before it was turned off by the subject. Analysis of this vigilance data did not reveal a consistent relationship between exposure duration and performance. However, the vigilance data clearly demonstrated pilot performance degraded as the weight moment of the helmet increased, and that acquisition times were shortest for weight moments of about

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20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Science Support Center	22b. TELEPHONE (Include Area Code) (334) 255-6907 22c. OFFICE SYMBOL MCMR-UAX-SS

19. Abstract (continued):

78 N cm. This conclusion, which is based purely on performance consideration, provides an independent confirmation of the Butler criterion which was derived from biomechanical analysis of head pitch accelerations and neck myoelectric activity.

Acknowledgments

We gratefully acknowledge Dr. Barclay Butler for initiating this work, Dr. Susan Lantz for refining the experimental design, and Dr. Lynn Caldwell for assisting in the statistical analysis. Also, the study would not have been possible without the Army helicopter pilots who volunteered to ride the MARS table.

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Introduction

Current design criteria for helmets worn by U.S. Army helicopter pilots are based primarily on considerations of neck and head injury during a crash. These criteria impose upper limits on the total mass (M) of the helmet and attached devices, and on the location of the center of mass (CM) of the overall system above the helmet basic horizontal plane with the assumption that the CM is located in the midsagittal plane. Unfortunately, some devices used by Army helicopter pilots are designed for mounting to the front of helmets, creating an imbalance which often is alleviated by attaching counterbalance masses to the rear of the helmet. While this may improve the ability of the pilots to perform their tasks, often it produces a helmet that exceeds design limits for M and CM locations. Furthermore, the effects of additional masses and imbalance on pilot fatigue and performance are not well documented, especially during extended missions where the pilot is exposed to whole-body vibration (WBV) of the helicopter.

The effects of WBV human performance have been extensively researched and reviewed (Dupuis and Zerlett, 1986). General guidelines for human exposure to WBV have been suggested in various international standards (e.g., ISO, 1985). Recent studies at the U.S. Army Aeromedical Research Laboratory (USAARL) investigated various aspects of head-supported devices related to the health and performance of helicopter aircrew under WBV. In a preliminary study conducted in 1989, Butler (1992) monitored head motion of six male volunteers, their head and neck postures, and neck electromyographic activity under sinusoidal WBV while varying helmet M and CM parameters. His data showed peak spectral response of head pitch acceleration always occurred at about 4 Hz, regardless of the degree of head and neck control exerted by the subject. However, relaxed subjects produced more pronounced peaks than those of subjects who strictly controlled their posture. In similar short-duration experiments by Griffin (1975), postures with maximum control produced transmissibility greater than unity at frequencies less than 15 Hz, indicating a stiffening of the spine.

In the full study, Butler (1992) tested 12 male volunteer subjects under sinusoidal vibration (3 m/s^2 amplitude) swept from 2 to 17 Hz at a sweep rate of 0.25 Hz per second. Each subject was tested with 12 helmet configurations obtained by using three masses centered at three locations in the midsagittal plane. The collected response data included head pitch accelerations, neck electromyographic (EMG) signals, and head/neck posture. The repeated measure design of the experiment allowed the analysis of biomechanical and EMG data, and led Butler to recommend a weight moment limit of 83±23 N·cm.

During the next USAARL study in this series, Lantz (1992) exposed 12 male volunteers to random WBV in 2-hour sessions. The vibration signatures were derived from a helicopter WBV environment. With the exception of the type and duration of WBV exposure, all other parameters and instrumentation were similar to the Butler (1992) study. In addition, subjects were required to acquire targets which were illuminated at random. Lantz reported degradations in vigilance due to increased target acquisition times and/or to a greater percentage of missed targets occurred at 45-60 minutes, 75-85 minutes, and 105-120 minutes. Posterior neck EMG responses showed time-dependent fatigue with shifts in the median spectral frequency after 2-hour exposure to random

WBV. The conclusions reached by Butler (1992) pointed to a need to verify the 83 N·cm weight moment criterion, and those reached by Lantz (1992) suggest that exposure times beyond 2 hours may reveal trends caused by extended exposures. This paper reports partial results from a followup study in which subjects were exposed to longer durations of WBV in an attempt to investigate both physiological and psychological effects of head-supported mass parameters.

Method

Since this is a followup to previous studies, the same USAARL multiaxis ride simulator (MARS) test facilities and many of the experimental procedures previously described in Butler (1992) and Lantz (1992) were followed. In addition, only performance-related data are presented here, while other biomechanical and EMG data from this study will be reported in appropriate forums.

Subjects

Due to the small sample size of 12 subjects, it was necessary to eliminate as many controllable sources of variation in the data as possible. For example, choosing only male subjects eliminated variations due to gender. Consequently, 12 active duty military male aviators with a current UH-60 or AH-64 rotary-wing aircraft rating were recruited from personnel assigned to Fort Rucker, Alabama. One of the subjects did not complete all four experiments and was dropped from the protocol. Another's lack of attention during portions of the experiments, evident from the collected data, also was excluded from the analysis. Relevant personal data on the remaining 10 subjects are given in Table 1.

Helmet configurations

A special head-worn device that can accommodate precise placement of additional weights and a light beam source was used to simulate four helmet configurations. These were formed by using 2- and 4-kg helmet weights, and weights were attached to the helmet as to place the CM at two offsets. One CM offset was located 5 cm directly above the AO joint, the other was 5 cm above and 4 cm forward of the AO joint. These configurations, designated here as helmets H20, H24, H40, and H44, were selected to represent realistic combinations of the SPH-4 Army aviator basic helmet, a pair of night vision goggles (NVG), an M43 face mask, and counterweights which usually are attached to the back of the helmets to balance the devices mounted to its front. Table 2 lists the properties of the four helmet configurations used in this study.

Table 1.
Relevant personal data of test subjects.

Subject	*Weight (lb)*	*Stature (in)*	*Sitting height (cm)*	*Age (years)*
1	187	74	93.7	28
3	180	75	93.5	28
4	189	70	87.6	34
5	186	73	95.3	27
6	193	72	94.5	23
7	181	68	85.5	26
8	250	75	95.4	27
10	183	70	85.7	30
11	200	72	97.5	30
12	190	76	95.6	29
Mean	193.9	72.5	92.4	28.2
S.D.	20.6	2.7	4.4	2.9

Table 2.
Properties of the four tested helmet configurations.

Config-uration	*Weight moment (N.cm)*	*Simulated devices*
H20	20	SPH4 basic helmet
H24	110	SPH4 + NVG
H44	290	SPH4 + NVG + M43
H40	200	H44 + counterweights

Helicopter ride simulation

Random vibration was chosen for the study because it resembles vibration signatures of helicopters. Vibration levels were band limited to 2-35 Hz and at levels similar to those experienced by aircrew in U.S. Army UH-60 and AH-64 helicopters flying at 125 knots. The frequency band of 35 Hz is a limitation of the hydraulic system of the MARS. This limitation was thought insignificant due to the low frequency of head pitch response which has been shown to be below 20 Hz (Wilder et al, 1982; and Butler 1992).

The subject was seated in a UH-60 seat complete with its seat and back cushions, and mounted atop MARS shake table platform. An exposure session was defined by the subject being tested and the helmet configuration he wore. Each session consisted of 4 hours exposure to a simulated helicopter ride during which the subject was required to perform several tasks, including a vigilance task to test his target acquisition speed, a target tracking task to test his precision in aiming his NVG, a synthetic work environment task to test his cognitive skills, and a rest period where his posture was monitored. These tasks lasted 15 minutes and were repeated 4 times an hour for 4 hours, resulting in 16 cycles of repeated measurements. Midway into the session, i.e., after completing eight cycles, the subject was given a short (5-10 minutes) break during which he was allowed to remove his helmet and leave the shake table.

Vigilance testing

For the purpose of this study, the performance measure of interest is vigilance. A subject's vigilance is quantified as the length of time required to both detect and accurately acquire a target using a helmet-mounted targeting device. Although many different measures might arguably give good insight into the effect of long duration flight exposure on pilot performance, the vigilance test was determined to be a particularly useful and appropriate performance measure for military helicopter pilots. Detection and acquisition of visual targets, a typical task performed by UH-60 and AH-64 helicopters pilots, was simulated by using four light-emitting diodes (LED) by requiring the subject to aim a light beam from a helmet-attached source at one of the four LED targets which were lit at random. The four targets, designated LED-1, 2, 3 and 4, were placed respectively at the upper left, lower left, upper right and lower right of a rectangular pattern which was 5.4 m wide, 1.1 m high, and was placed about 3 m in front of the subject. This arrangement was designed to require large head motions in different directions to force activation of different neck muscle groups.

Each LED remained lit until the subject turned it off by hitting it with his light beam for about 1 second. After each target acquisition, the subject returned his head to a neutral position by looking straight ahead to the center of the rectangle and remained vigilant for the next LED lighting. To eliminate learned anticipation of the next target, both the order (1 to 4) of the LEDs and time intervals (5 to 10 seconds) between them were varied at random. Each LED was lit approximately 7 times during the 5-minute vigilance segment of each cycle, requiring the subject to acquire a target nearly 30 times per 15-minute cycle, or 480 times per 4-hour test session. Due to slight inconsistencies in the manner in which tests were started and ended, only data collected from cycles 2 through 15 were chosen for subsequent analysis. The LED targets were connected to an electronic circuit that identified the LED and measured the duration for which it was turned on. This response time, which is the primary dependent variable in this investigation, was recorded to a disk file for later processing. Independent variables include subject (1 through 10), helmet weight moment (20, 110, 200 and 290 N·cm), elapsed exposure time (0 to 4 hours, in 15-minute steps), and target location (1 through 4).

Results and discussion

Analysis of variance

A three-way repeated measures analysis of variance (ANOVA) was performed to determine the main effects and interactions due to helmet weight moment, duration of exposure, and target location. Two main factors (target location and helmet weight moment) were determined to have statistically significant effects on the pilot's speed of target acquisition. The effect of the third factor (exposure duration) was not determined to be statistically significant. The mean pilot response (i.e., speed of target acquisition), standard deviation, and error are given in Table 3. During data analysis, the Huynh-Feldt adjusted degrees of freedom were used to evaluate the significance of interactions when sphericity assumptions were violated.

Table 3.
Summary statistics for the two significant main factors.

Factor	*Mean response (seconds)*	*Standard deviation (seconds)*	*Standard error (seconds)*
Helmet 20	2.253	0.589	0.025
Helmet 24	2.189	0.458	0.019
Helmet 40	2.363	0.381	0.016
Helmet 44	2.539	0.472	0.020
LED 1	2.252	0.502	0.021
LED 2	2.327	0.486	0.021
LED 3	2.288	0.491	0.021
LED 4	2.477	0.486	0.021

Effect of LED location. Because the spatial distribution of the LED targets forced the use of different muscle groups to acquire different targets, there was a potential effect of LED position on the response time. Data analysis confirmed that target position indeed was a statistically significant factor affecting vigilance performance ($F(3,27)=10.06$, $p=0.0002$). In particular, contrasts among the means indicate that the mean response time for LED 4 was greater significantly than the mean response times for LEDs 1 , 2, and 3. No significant difference was noted among the mean response times for LEDs 1, 2, and 3. This effect, as well as the standard error, is illustrated in Figure 1. Although the effect of LED position was found to be statistically significant, it is of somewhat limited interest because that actual target location is largely random and beyond the control of the aviation equipment designer. In addition, no significant interaction was noted between either helmet weight moment or exposure duration and LED position. However, testing a variety of target locations helped to provide a realistic environment in which to evaluate the effects of helmet weight moment and exposure duration.

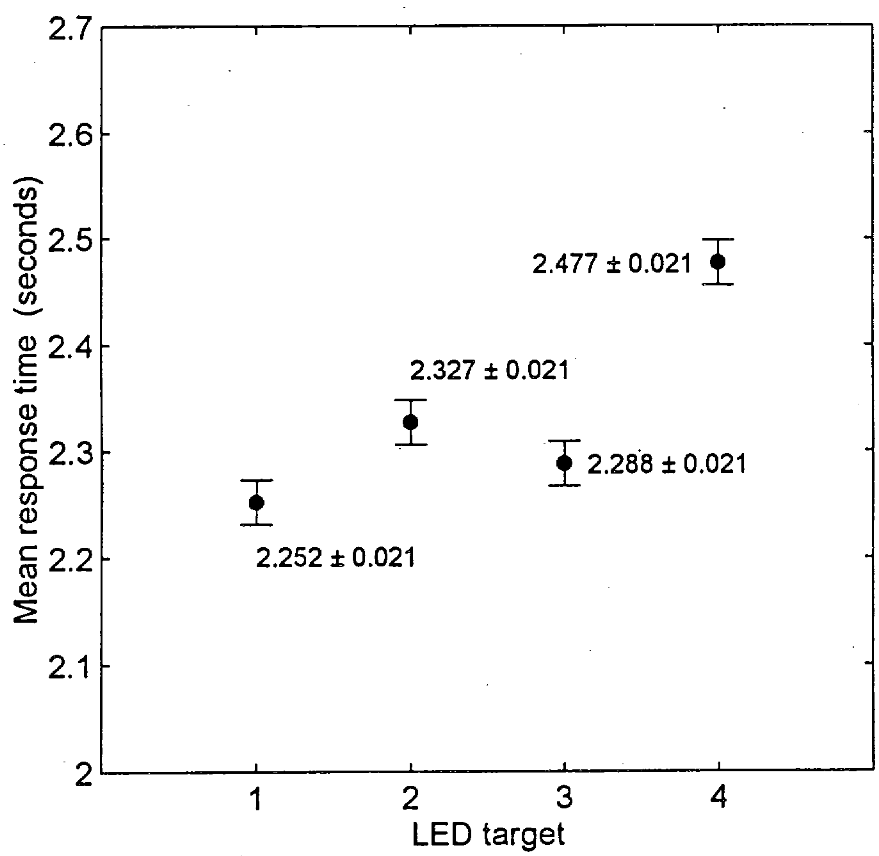

Figure 1. Effect of LED target position on the speed of target acquisition.

Effect of exposure duration (cycle). Prior to testing, it was hypothesized that a degradation in the vigilance performance measure might occur as a result of elapsed time. However, ANOVA indicated the effect of exposure duration on vigilance was not significant ($F(13,117)=1.46$, $p=0.2026$). No significant interactions between exposure duration and either helmet configuration or LED position were found.

Effect of weight moment. The ANOVA revealed a significant effect of helmet weight moment on vigilance performance ($F(3,27)=4.20$, $p=0.0237$). Contrasts among means indicate that the mean response time associated with helmet configuration H44 is greater significantly than that of helmet H24 ($F(1,9)=23.51$, $p=0.0009$). In addition, the mean response time associated helmet H40 is greater significantly than that associated with helmet H24 ($F(1,9)=7.31$, $p=0.0243$). Figure 2 shows the contrast among mean response times, with standard errors included, as a function of helmet weight moment. No significant interactions between helmet configuration and either LED position or exposure duration were noted.

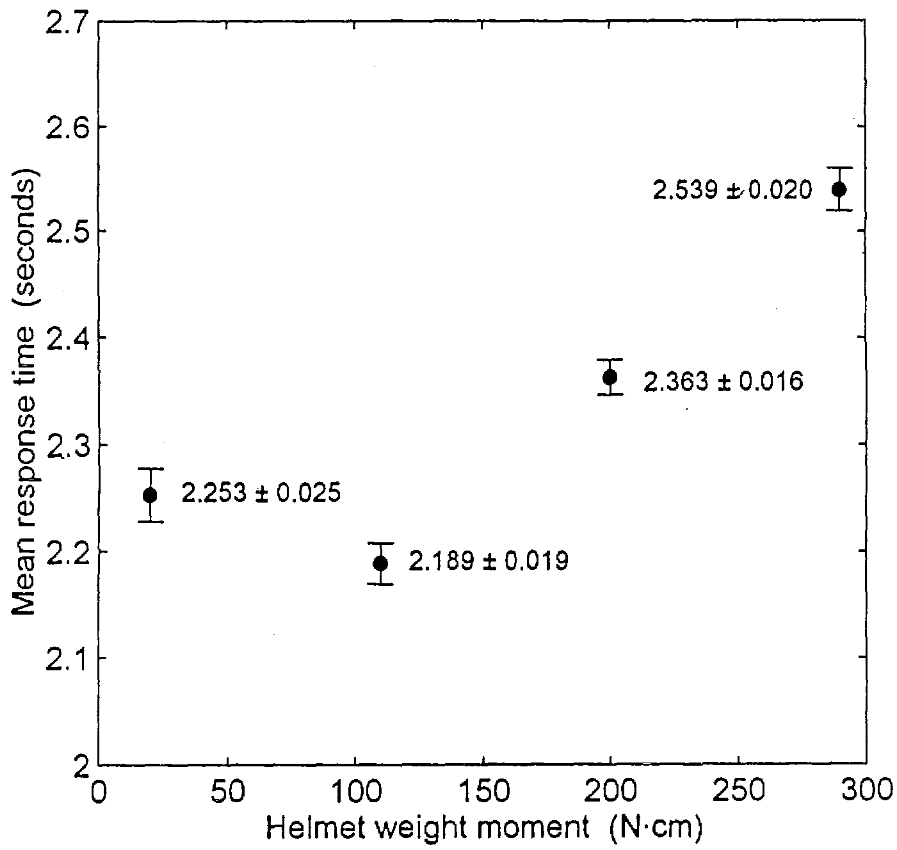

Figure 2. Effect of helmet weight moment on the speed of target acquisition.

Quadratic model

Increasing helmet weight moment may have various effects on pilot vigilance. For example, a relatively small weight moment of the helmet can act as a beneficial damping force, effectively attenuating the response of the head and neck to WBV. On the other hand, increasing the weight moment past a certain point tends to load the head and neck, causing potential performance degradation. Such effects were observed by Butler (1992) who identified a helmet weight moment of 83 N·cm as an optimal configuration based on analysis of head pitch accelerations and neck myographic activity. The distribution of mean response times, shown in Figure 2, is consistent with the assumption that a minimum point exists and suggests a second order dependency of pilot vigilance on helmet weight moment. The mean response times were, therefore, fitted to a quadratic function of weight moments, resulting in

$$T = 2.2617 - 0.1156\,M + 0.0742\,M^2$$

where T is the response time (seconds) and M is the helmet weight moment (N·cm). A graph of this quadratic function, which has a unique minimum at 78 N·cm, is shown in Figure 3. Since only four helmet configurations were tested, it is unclear whether this model accurately indicates the location of the optimal weight moment, but it does suggest that future experiments should focus on helmet configurations with weight moments in the 50-100 N·cm region.

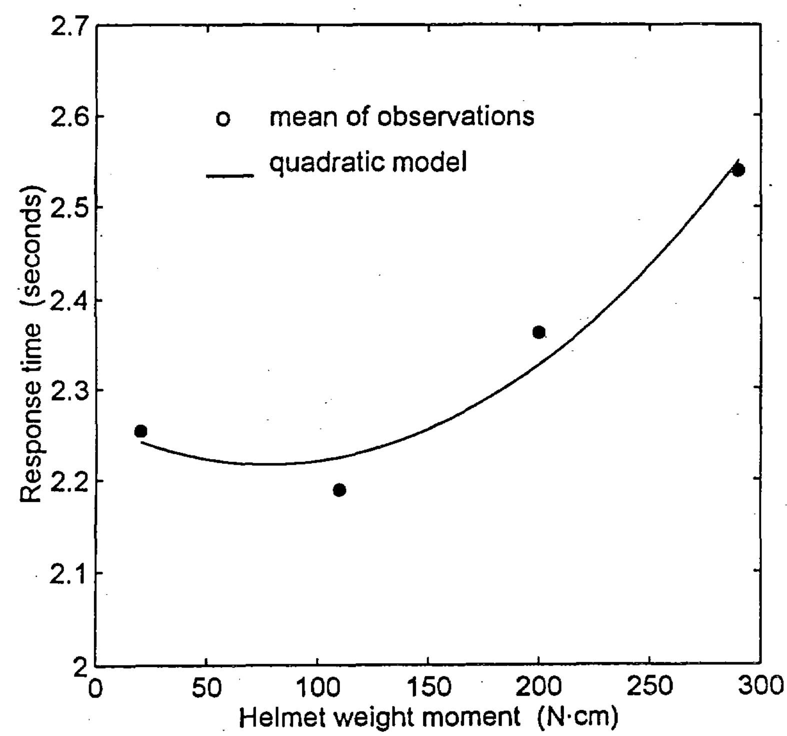

Figure 3. Quadratic model to predict pilot's response time as a function of helmet weight moment.

Conclusions

Analysis of vigilance data from this study did not reveal a consistent relationship between exposure duration and performance. However, the data clearly demonstrated that pilot vigilance degraded as the weight moment of the helmet increased and that target acquisition times were shortest for weight moments of about 78 N·cm. This conclusion, which is based purely on performance consideration, provides an independent confirmation of the Butler criterion which was derived from biomechanical analysis of head pitch accelerations and neck myoelectric activity. Biomechanical analysis of EMG data and other performance and posture measures from this study, currently underway, may support this conclusion. However, the results do suggest that weight moments in the 50-100 N·cm region should be the focus of future investigations.

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